HEAVY METALS REMOVAL IN ANIMAL WASTEWATER USING WATER HYACINTHS (*Eichhornia crassipes)*

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DECLARATION

No portion of the work in this dissertation has been submitted in support of an application for another degree of qualification of this or any other university or institution of higher learning.

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Abstract

Animal wastewaters contain heavy metals which were due to their presence in animal's diet. This study was conducted to observe the uptake of a mixture of heavy metals such as copper (Cu), cadmium (Cd), lead (Pb) and zinc (Zn) by water hyacinths for a period of four days and leaching of heavy metals in treated and untreated wastewater using living and dead water hyacinths for a period of 7 days. Simultaneously, blank experiments were carried out for comparison. Water hyacinths accumulated higher concentration of heavy metals in the root than in the stems and leaves. The results of the present study showed that Cd absorption was the lowest compared to other metals due to its toxicity. The absorption of Zn and Cu was due to their role as micronutrients and the absorption of Cu ranged from relatively low to relatively high. There was a considerable amount of Pb being absorbed by water hyacinths the roots of water hyacinths. Generally, in Experiment 2, only Cd and Cu was leached whereas in Experiment 3, Cd, Cu and Zn was leached. However, the amount of heavy metals leached was little compared to the absorption. Thus, water hyacinth can be regarded as a heavy metal decontaminator in animal wastewater treatment, rather than as a pollutant.

Key words: Heavy metals, Water hyacinths, Absorption, Leaching

Abstrak

Air sisa buangan daripada haiwan mengandungi logam berat kerana ia terdapat dalam makanan harian haiwan. Kajian ini telah dijalankan untuk memerhatikan penyerapan sesuatu logam berat misalnya kuprum (Cu), cadmium (Cd), plumbum (Pb) dan zink (Zn) dalam pokok keladi bunting untuk tempoh 4 hari dan pembuangan logam berat dalam masing-masing air sisa yang dirawat dan tidak dirawat oleh pokok keladi bunting yang hidup dan yang mati dalam tempoh 7 hari. Pada masa yang sama, eksperimen kawalan dijalankan untuk tujuan perbandingan. Pokok keladi bunting akan mengumpul logam berat dengan kepekatan yang lebih tinggi dalam akar berbanding batang dan daun. Keputusan untuk kajian ini membuktikan bahawa penyerapan Cd adalah terendah jika dibandingkan dengan logam berat lain disebabkan oleh ketoksikannya. Penyerapan Zn dan Cu adalah disebabkan oleh peranannya sabagai mikro nutrien dan penyerapan Cu bearda dalam lingkungan rendah ke tinggi. Terdapat juga unsur Pb yang telah diserap oleh akar pokok keladi bunting. Untuk analisis pembebasan logam berat (Eksperimen 2 dan 3), semua penyerapan adalah rendah jika dibandingkan dengan Eksperimen 1. dalam Eksperimen 2, Cd dan Cu dibebaskan manakala dalam Ekserimen 3, Cd, Cu dan Zn dibebaskan. Namun, pembebasan logam berat adalah sedikit jika disbanding dengan penyerapannya dalam Eksperimen 1. Maka, kesimpulannya, peranan pokok keladi bunting boleh dikelaskan sebagai pembersih logam berat dalam air sisa buangan daripada sebagai bahan pencemar.

Kata kunci: Logam berat, Pokok keladi bunting, Penyerapan, Pembebasan

1 INTRODUCTION

Wastewater contains a mixture of heavy metals and these heavy metals need to be removed before discharging them into rivers. Animal wastewaters contain high concentration of organic matters, nutrients and some pathogenic microorganisms (Polprasert *et al.*, 1992). The amount and composition of animal wastes excreted per unit time vary widely and is dependent on the total live weight of the animal, the species of the animal, the animal's size, age, feed, water intake, climate and many more (Polprasert, 1996). In some areas of developing countries, animal wastewaters are discharged on land or into receiving water directly. This causes pollution problems such as depletion of dissolved oxygen (DO), eutrophication and public health hazards (Polprasert *et al.*, 1992).

The term 'heavy metal' has become well-established in the literature of environmental pollution. In constructed wetlands, plants act as a 'polishing system' in removal of heavy metals from contaminated water (Matagi *et al.*, 1998). Examples of heavy metals include zinc (Zn), cadmium (Cd), copper (Cu) and lead (Pb). Zinc and copper supplements have been added into animal diets, the former to correct possible deficiencies and the latter to improve the growth rate (Lepp, 1981). Unlike organic pollutants, heavy metals cannot be degraded by chemical or biological processes (Delgado *et al.*, 1993; So *et al.*, 2003). Therefore, to remediate the aquatic environment, the toxic metals should be concentrated in a form that can be extracted conveniently, possible for reuse or at least for proper disposal (So *et al.*, 2003).

Recently, there has been much interest in the use of constructed wetlands to remove toxic metals from contaminated soils, sediments and waters (Horne, 2000). The interest of study has focused on aquatic macrophytes such as water hyacinth (*Eichhornia crassipes)* and water lettuce *(Pistia stratiotes)* as promising candidates for pollutant uptake and good bioindicator of water pollution by heavy metals in aquatic systems (Wolverton and McDonald, 1979; Martin and Coughtrey, 1982; Gersberg *et al.*, 1986; Bishop and Eighmy, 1989; Delgado *et al*., 1993; Jenssen *et al.*, 1993; Ozimek *et al.*, 1993; Sen and Bhattacharyya, 1994; Aoi and Hayashi, 1996; Maine *et al.*, 1998, 1999). Water hyacinth is one of the plant species that attracted considerable attention because of its ability to grow in heavily polluted water and also its capacity for metal ion accumulation (Gopal, 1987; Ismail *et al.*, 1996; Jamil *et al.*, 1998; Zhu *et al.*, 1999). Restoration of a vegetation cover can assist environmental stabilization, pollution control and improved aesthetics (Deng *et al.*, 2006).

Although there are other conventional methods such as primary treatment via physical sedimentation mechanism (Polprasert, 1996) and chemical treatments that involve precipitation, adsorption and ion-exchange mechanism through adding of chemicals (Tchobanoglous and Burton, 1991), aquatic macrophytes treatment systems have more advantages as they require little energy for operation and they are capable of removing a spectrum of contaminants (Reed *et al.*, 1988; USEPA, 1988; Tchobanoglous and Burton, 1991). Aquatic macrophytes treatment systems are also free from usage of chemicals that are toxic both to humans and environment.

However, water hyacinth litter leaches substantial quantities of inorganic and organic compounds during its initial, as well as later phase of decay (Reddy and Sacco, 1981;

Varghese, 1991; Gaur *et al.*, 1992). Therefore, this study is conducted to determine the uptake of heavy metals by living water hyacinth and the releases of heavy metals by living and dead water hyacinths in order to investigate its role as a source of water contamination or purification.

1.1 Objective of this Study

The objective of this study was to determine and compare the uptake of a mixture of heavy metals, namely, copper (Cu), zinc (Zn), cadmium (Cd) and lead (Pb) from wastewater using water hyacinth and the release of heavy metals from this plant.

2 LITERATURE REVIEW

2.1 Importance of Wastewater Treatment

Animal wastewaters contain high concentration of organic matters, nutrients and some pathogenic microorganisms (Polprasert, 1992). Besides, heavy metals are also present in wastewaters as a result of animal's diet (Lepp, 1981). Toxic organic matters, excessive nutrients, some pathogenic microorganisms and heavy metals impose various adverse effects to environment and human's health. Fish and wildlife bioaccumulate excessive levels of heavy metals and will jeopardize human's health if they are consumed (Owen and Chiras, 1995). Lead causes irreversible brain damage, especially in children whereas copper and zinc are toxic to fish (Owen and Chiras, 1995). Cadmium manifests its toxicity by affecting enzymes, metabolites of glucose metabolism (Soengas *et al.*, 1996) and fatty acid biosynthesis (Steibert and Kokot, 1980). It is also reported that cadmium affects cell proliferation and development and is implicated in apoptosis (Jia *et al.*, 2002; Bisova et al., 2003; Waisberg et al., 2003; Yang et al., 2004).

2.2 Sources of Heavy Metals

There are a few sources of heavy metals of terrestrial environment which leads to metals contamination in water. There are natural sources such as surface mineralizations, volcanic outgassing or spontaneous combustions leads to terrestrial environments. The use of metal-containing agricultural sprays and the disposal of wastes from mining and mills caused heavy metal pollution in soil (Lepp, 1981), which will be eroded into rivers and caused water pollution. Effluent from large industrial sources and agriculture which are discharged directly into receiving waters are also the sources of heavy metal contamination in water. Livestock farm waste also poses as a source of heavy metals due to the heavy metals consumed in feed and is excreted in solid or liquid form as excreta (Lipan, 2005). From the study done by Lipan (2005), the average concentrations of heavy metals range from 1.06 to 327.75 mg/kg in feed and from 11.67 to 1185.50 mg/kg in waste. The concentration of copper (Cu) was the highest in feed followed by zinc (Zn), cadmium (Cd), chromium (Cr), nickel (Ni) and lead (Pb).

2.3 Functions of Aquatic Macrophytes

Aquatic macrophytes usually refer to larger aquatic plants growing in wetlands. The term includes aquatic vascular plants, aquatic mosses, and some larger algae which have easily visible tissues (Brix 1997). Aquatic plants are known to accumulate heavy metals (Wolverton and McDonald, 1976; Yahya, 1990; Vesk and Allaway, 1997; Vesk *et al.*, 1999; Ali and Soltan, 1999; Soltan, 1999; Banuelos and Lin, 2004; Dickinson and Pulford, 2004; Ghabbour *et al.*, 2004; Embrick *et al.*, 2005; Johansson *et al.*, 2005; Vogel-Mikus *et al.*, 2005; Singh and Sinha, 2005; Lazaro *et al.*, 2006). Wetland plants such as water hyacinth (*Eichhornia crassipes*) (Vesk *et al.*, 1999) and duckweed (*Lemna minor*) (Zayed *et al.*, 1998) can accumulate heavy metals in their tissues. Development of metal tolerance is a major way to reduce the harmful effects of excessive exposure to heavy metal ions (Tyler *et al.*, 1989). However, the degree of metal uptake by wetland plants varies greatly (Qian *et al.*, 1999; Deng *et al.*, 2004). Laboratory studies of aquatic macrophytes have demonstrated that these plants are effective in removing metals from polluted water and it is found that the metal concentrations of the plant and the water were correlated (Muramoto and Oki, 1983; Lee and Hardy, 1987). Aquatic plants removed metal via filtration, adsorption, cation exchange and through plant-induced chemical changes in the rhizosphere (Dunbabin and Bowmer, 1992; Wright and Otte, 1999). Field studies have shown that water hyacinth accumulate metals in roots and leaves (Ajmal *et al.*, 1987; Zaranyika and Ndapwadza, 1995) and the heavy metals accumulated in the roots are more than the petioles and least in the leaves of water hyacinth (Cooly and Martin, 1979). Metal accumulation by wetland plants is influenced by various factors (Reddy, 1983; Gersberg *et al.*, 1986) thus, the effectiveness of wastewater treatment using aquatic macrophytes can be greatly enhanced by careful selection of plant species (Deng *et al.*, 2004). Metal accumulation by aquatic macrophytes is affected by variations in plant species, the growth stage of the plants, and element characteristics that control absorption, accumulation and translocation of metals (Deng *et al.*, 2004).

2.4 Current Wastewater Treatment Methods to Remove Heavy Metals

Contaminants in wastewater are removed by physical, chemical and biological means (Tchobanoglous and Burton, 1991). However, physical and chemical processes are commonly used to remove heavy metals in conventional methods whereas biological processes are used to remove biodegradable organic substances (Tchobanoglous and Burton, 1991).

Treatment methods in which the application of physical forces predominates such as screening, mixing, flocculation, sedimentation, flotation, filtration and gas transfer are typical unit operations (Tchobanoglous and Burton, 1991). Primary treatment, which involves sedimentation, is the separation from water, by gravitational settling of suspended particles heavier than water. It is one of the most widely used unit operations in wastewater treatment. According to Owen and Chiras, (1995), the major function of primary treatment is to separate the solids from the wastewater. After screening out of large objects, stream of wastewater is pumped to settling tanks where solids settle to the bottom and is ready for secondary treatment, which involves the use of bacteria to decompose organic matter.

Addition of chemicals to form precipitates of hydroxides and complexes were also used to treat heavy metals in wastewater treatment. During wastewater treatment, nearly all of the particle-associated metals are removed through settling, while dissolved metal concentrations remain largely unaffected by treatment (Oliver and Cosgrove, 1974; Nielsen and Hrudey, 1983; Lester, 1983; Stephenson *et al.*, 1987, Ekster and Jenkins, 1996). The removal of dissolved metals often is hampered by the presence of ligands that prevent metal adsorption to settleable particles (Laxen and Harrison, 1981; Sterritt and Lester, 1981; Sedlak *et al.*, 1997; Wang *et al.*, 1999). According to a study done by Ridge and Sedlak, (2004), ferric chloride ($FeCl_3$) is added during primary wastewater to enhance the removal of particles and pollutant metals (Ødegaard, 1988; Shao *et al.*, 1996; Jiménez and Landa, 1998) and promote the conversion of pollutant metal–EDTA species to $FeEDTA^-$ which thereby improve Cu and Zn removal during wastewater treatment because Cu and Zn are the most prevalent pollutant metals that form strong complexes with EDTA in wastewater. On average, total concentration of Cu and Zn were 18±7% and 18±8% lower, respectively (Ridge and Sedlak, 2004). In addition, precipitation of hydroxides is used to treat heavy metals using addition of different dosages of lime at pH 8.5, 9.0, 9.5, 10.0, 10.5 and 11.0 (Charerntanyarak, 1999). The effluent was analyzed for concentration of Zn and Cd. Polymer was added to further decrease the heavy metals concentrations and the effluent was analyzed (Charerntanyarak, 1999). Finally, sodium sulphite (Na_2S) was added to precipitate heavy metals as the hydroxide (Charerntanyarak, 1999). Removal of Zn and Cd from the wastewater can be accomplished by precipitation as the hydroxide at elevated pH, but values of pH 9.5 or greater are necessary for effective removal (Charerntanyarak, 1999). The more effective appears feasible when technology for sulphide precipitation is used in secondary treatment (Charerntanyarak, 1999).

The use of a weak electrolyte macroporous carboxylate resin to retain metals for ion exchange is another process done to treat heavy metals (Tiravanti *et al.*, 1997). In this process, H_2O_2 in NaCl and NaOH at pH 12 was used to elute chromium (Cr) retained in resin, after oxidation to chromates. Cr (VI) solution was reduced to Cr (III) with Na_2S in acidic media through Cr^{3+} and Na^+ ion exchange and a more concentrated solution was obtained by $Cr(OH)_3$ (Tiravanti *et al.*, 1997). The sufficiently high pH value to avoid hydrolysis and inactivation of the functional groups toward chromium species, but sufficiently low to avoid precipitation of metal hydroxides onto the resin beads is 8.5-9.0 (Tiravanti *et al.*, 1997). This process allow the removal and separation of about almost pure (99.9%) Cr from other interfering metals and organic compounds (Tiravanti *et al.*, 1997).

Many models of adsorption for cations and anions on surfaces have been developed considering variations in parameters such as pH, adsorbent and adsorbate concentration (Osake *et al.*, 1990a, b; McKinley and Jenne, 1991; Cowan *et al.*, 1991; Gagnon *et al.*, 1992). The adsorption of metals on alumina has been shown to be pH dependent and the precipitation or dissolution of the aluminium oxide affects the concentration of heavy metals (Yabe, 1995). In the study conducted by Yabe and Oliveira, (2003), sand, silica, coal and alumina were chosen for the removal of contaminants. A metal removal system was constructed with connecting tubes to contain the solid adsorbent. The first tube, filled with a solid adsorbent, received the waste flow and flowed through the second tube and so on. At the end, a container collector allowed the periodic evaluation of the system adsorption capacity. This study shows that alumina was considered the best adsorbent solid and presented a high efficiency in removing ferum (Fe), chromium (Cr), lead (Pb), nickel (Ni), copper (Cu) and zinc (Zn).

2.5 Mechanism of Aquatic Macrophytes

Heavy metals are removed from wastewater by plant through physical sedimentation and chemical processes. Each mechanism is affected by the design and management of the aquatic system, the quality of the effluent wastewater and climatic environmental factors (Polprasert, 1996). During aquatic treatment, the aquatic environment should be controlled to optimize the precipitation, ion exchange and absorption removal mechanism (Polprasert, 1996). For physical sedimentation mechanism, heavy metals have incidental effect in which solids and other constituent contaminants undergo gravitational settling in pond (Polprasert, 1996).

For chemical treatment, removal and conversion of contaminants is brought by the addition of chemicals or by other chemical reactions (Tchobanoglous and Burton, 1991). The most common example used in wastewater treatment is precipitation, adsorption and ion exchange (Tchobanoglous and Burton, 1991; Polprasert, 1996). Precipitation is accomplished by producing a chemical precipitate that will settle. This precipitate will contain both the constituents that may have reacted with the added chemicals and the constituents that were swept out of the wastewater as the precipitate settled (Tchobanoglous and Burton, 1991). The mechanism of adsorption involves removal of specific compound from the wastewater on solid surfaces using the forces of attraction between bodies (Tchobanoglous and Burton, 1991) whereas ion exchange involves the exchange of metal ions with other ions. Heavy metals have primary effect of forming or coprecipitating with insoluble compounds and adsorbing on substrate and plant surfaces for precipitation and adsorption mechanism (Polprasert, 1996). For plant absorption mechanism, heavy metals have a secondary effect in which under proper conditions, significant quantities of these contaminants will be taken up by plants (Polprasert, 1996).

2.6 Advantages of Using Aquatic Macrophytes

Floating aquatic macrophytes treatment systems are land intensive and require little energy for operation (Isaacson, 1991). They are capable of removing a spectrum of contaminants such as organic matter, suspended solids, nutrients, heavy metals, trace organics and pathogens (Reed *et al.*, 1988; USEPA, 1988; Tchobanoglous and Burton, 1991). Conventional systems require more construction and equipment and the processes are subject to greater operational control (Polprasert, 1996). There is a lack of consistency in meeting discharge requirements, high costs for chemicals, handling and disposal of the great volumes of sludge resulting from the addition of chemicals and the adverse effects caused by the usage of chemicals such as chlorine which is toxic and very corrosive (Tchobanoglous and Burton, 1991).

2.7 Previous Studies on Aquatic Macrophytes

In United States of America, Skinner *et al.*, (2006) uses water hyacinth, water lettuce, zebra rush and taro to accumulate mercury due to either their netlike root structure, or their prevalence in wetland areas. The plants are exposed to various concentrations of mercury for 30 days. After 30 days, the concentrations of mercury accumulated in the root tissues of the four species of plants in μg g^{-1} are shown as below:

Species	0 μg/L Hg	0.5 μg/L Hg	2 μg/L Hg
Water hyacinth	22.6	23.7	83.2
Water lettuce	0.0891	15.4	26.2
Zebra rush	-0.00495	2.46	6.99
Taro	-0.031	0.822	3.88

From the results, it could be observed that water hyacinth has the highest accumulation of metal compared to the other plants. The higher the concentration, the higher is the uptake.

A study in Egypt (Soltan and Rashed, 2003) uses water hyacinth to treat cadmium (Cd), cobalt (Co), chromium (Cr), mangan (Mn), nickel (Ni), lead (Pb) and zinc (Zn) grown in different media such as distilled water, Nile water, wastewater from Kima drain in Aswan, Egypt and different concentrations of heavy metals. The accumulations of metals by water hyacinth in μg g^{-1} dry matter ranges from:

Heavy metals	Root	Aerial
Cadmium (Cd)	10-2060	2-1200
Cobalt (Co)	52-2680	10-2475

Chromium (Cr)	135-3000	45-3000
Copper (Cu)	129-2950	47-1900
Mangan (Mn)	1875-2110	635-1900
Nickel (Ni)	95-1400	40-1500
Lead (Pb)	65-34950	30-1030
Zinc (Zn)	275-5000	80-5400

These results show that the uptake of heavy metals in roots is higher compared to the aerial parts.

Das and Jana (2004) did a study in India to examine the distribution of cadmium concentrations of water in relation with the tissues of freshwater mussel and water hyacinth. In this study, the concentrations of cadmium in leaves as well as in roots were estimated. Water hyacinths collected from Mundiali pond has a concentration as high as 125-152 µg/g dry weight of cadmium in the root's tissue and 21-63 µg/g dry weight in the leaves. Water hyacinths collected from other ponds have lower concentrations of cadmium in their tissues which are 40-108 µg/g dry weight in root and 9-43 µg/g dry weight in the leaves. This study also reveals that the analysis of water hyacinths from different ponds all reveals the same trend, which is the roots of water hyacinths accumulate more cadmium compares to the aerial part.

In Argentina, Maine *et al.*, (2000) uses a group of floating aquatic macrophytes, which includes water hyacinth to study the uptake of cadmium. From this study, it has been stated that water hyacinths were highly efficient in the cadmium uptake. The increase in plant tissues occurred especially in the roots and was linearly related to the quantity of cadmium and the cadmium translocation to the plant aerial part was slower than the sorption by roots, even though it occurred since the first moment of plant contact.

Vesk and Allaway, (1997) has conducted a study using water hyacinth to treat copper (Cu) and lead (Pb) in the Northwestern arm of Kensington Pond, Centennial Park, Sydney where stormwater run-off from the heavily urbanized catchment. The results of this study show that the accumulation of lead in the roots of the water hyacinth is between 145±15 and 1110±145 µg g^{-1} dry mass whereas the accumulation of copper is between 14.7±7.0 and 303±108 µg g^{-1} dry mass. It has also been shown that a plant with numerous thin roots would accumulate more metals than one with few thick roots and this may be an effect of the greater surface area to volume ratio for fine roots than coarse roots (Vesk and Allaway, 1997).

Another study was done in United States of America using water hyacinths as pollution monitor for the accumulation of arsenic, cadmium, lead and mercury (Chigbo *et. al.*, 2003). Cadmium and lead showed a concentration ratio in leaves to stems of about 1:1. The leaf concentration of arsenic was the lowest of the metals at 0·3428 mg g^{-1} of dried plant material whilst the leaf concentration of cadmium was highest at 0·5740 mg g^{-1}.

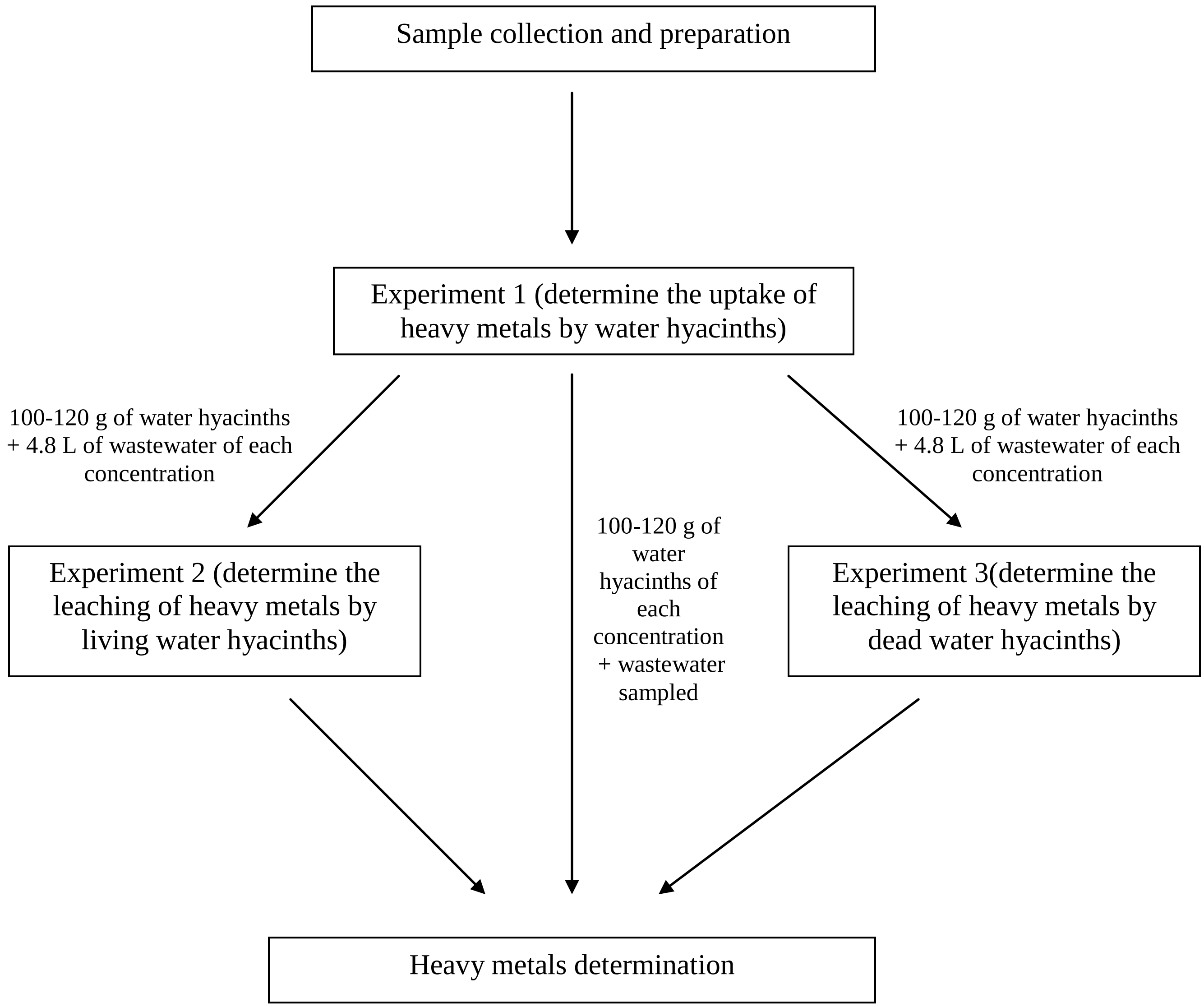
In a research done in Spain by Delgado et al. (1993), the uptake capacity of cadmium, chromium and zinc was studied. Among the three elements, cadmium was the most toxic element, showing some necrosis in the plant when the concentration in the solution was higher than 2.5 ppm (Miller and Koeppe, 1977; Street et al., 1977). When the concentration rate of cadmium was higher than 0.5ppm, productivity of the water hyacinths has reduced drastically (Page et al., 1072; Root, 1975). For chromium treatment, productivity decreased when the concentration was higher than 9 ppm whereas for zinc, at concentration of 9 ppm, a 30% weight reduction occurs (Delgado et al., 1993). For chromium, it was observed that the absorption was greater in the first 24 hours of the experiments. For zinc and cadmium, the absorption was constant during the first 24 hours but a strong decrease of metal concentration in the solution was observed from the third day. This study shows that different metals have different rate of accumulation by water hyacinth.

In United States of America, O'Keeffe *et al.* (1984) have studied the uptake of cadmium by water hyacinth when affected by three types of solution factors which are the concentration of cadmium, the effect of pH and the concentration of zinc. In their study, water hyacinths were exposed to cadmium concentrations ranging from 0.0001 to 1000ppm and it was found out that the plant is capable of removing cadmium over the entire range. Initially, there is a rapid uptake which has duration of about 4 hours but after that, the rate of uptake was much slower for at least 72 hours in which a nearly linear rate of decrease becomes apparent. The uptake of cadmium by water hyacinths over a pH range of 2 to 10 was also examined. It was observed that the uptake of cadmium increases with increasing pH to a maximum at pH 5. At higher pH values, the trend was reversed. In this study, water hyacinths were also examined for their ability to uptake cadmium in the presence of zinc. Although the uptake curves obtained was quite similar to those where zinc was not present, however it was observed that increasing concentrations of zinc causes the rate of cadmium uptake to decrease.

A study on the leachate of water hyacinth decay that affects the growth of chlorophyta known scientifically as *Scenedesmus obliquus* was done by Sharma *et al.* (1992) in India. In their study, it was revealed that decay water hyacinths stimulate the growth of alga in the first 10 days due to the excess nutrients that are released from the litter by physical leaching and by microbial processes. However, the leachate of 10 to 35 days of decay becomes toxic to the alga. This study provides clear experimental evidence that the decaying water hyacinth litter releases some toxins that cause acute toxicity to *Scenedesmus obliquus*.

From the literature review obtained, there were many studies done that involved water hyacinths. For example, in the study of Skinner *et al.* (2006), it was revealed that water hyacinths have the highest accumulations of metal compared to other aquatic macrophytes tested. The studies done by Soltan and Rashed (2003), Das and Jana (2004), Maine *et al.* (2000) and Vesk and Allaway (1997) show that the roots of water hyacinths uptake more metals compare to the aerial part. Another study by Chigbo *et al.* (2003) reveals that cadmium is accumulated the most by water hyacinths compared to other metals such as arsenic, lead and mercury. Delgado *et al.* (1993) found out that different metals have different rate of uptake by water hyacinths. O'Keeffe *et al.* (1984) studied the uptake of cadmium by water hyacinth when affected by three types of solution factors which are the concentration of cadmium, the effect of pH and the concentration of zinc and has concluded that the uptake of cadmium by water hyacinths depend on the concentrations of cadmium, the pH and the presence of other metals. However, there are only little studies done on the leachate of decaying water hyacinth and in the study of Sharma *et al.* (1992), it was only briefly mentioned that decaying water hyacinths releases some toxins.

3 MATERIALS AND METHODS



Scheme 1: Methodology of the experiment